

**TITLE:** ANALYZING-POWER FORMALISM FOR THREE-BODY FINAL STATES

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**SUBMITTED TO:** 5th International Symposium on Polarization Phenomena  
in Nuclear Physics, Santa Fe, NM, August 11-15, 1980

**MASTER**

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# ANALYZING-POWER FORMALISM FOR THREE-BODY FINAL STATES<sup>\*</sup>

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In connection with measurements<sup>1</sup> being carried out on the three-nucleon reaction  $^1\text{H}(\vec{d}, pp)n$ , we have derived various relationships important for extraction of analyzing powers from data on reactions involving three particles in the final state. We present here, for spin-1/2 and spin-1 polarized beams, several of the pertinent results, detailed derivations of which will appear elsewhere.<sup>2</sup>

We choose a Cartesian coordinate system at the reaction site to describe the vector and tensor analyzing powers and take the z axis to be in the beam direction. With respect to the symmetry axis Z of the ion source, the beam polarization is described by its vector polarization  $p_z$  and its tensor polarization  $p_{zz}$ . At the reaction site, this "quantization axis" makes a polar angle  $\theta$  with respect to the beam direction (z axis) and an azimuthal angle  $\phi$  with respect to the y axis. For a two-body final state it is conventional to take the y axis perpendicular to the reaction plane. For a three-body final state the two geometries of Fig. 1 would appear reasonable, where  $\phi_1$  and  $\phi_2$  are the azimuthal angles of the two particles detected<sup>1</sup> in a kinematically complete experiment, and the momenta are viewed in projection on the xy plane. In certain circumstances the symmetric choice illustrated in Fig. 1(b) introduces significant simplifications, and because of this we propose that Fig. 1(b) be adopted as a y-axis convention for work involving three-body final states.

It will be recalled that, for two-body final states as described in the conventional coordinate system, parity conservation requires that the analyzing powers  $A_x$ ,  $A_z$ ,  $A_{xy}$ , and  $A_{yz}$  vanish. The same is true for a kinematically incomplete experiment in which only one of

the three particles in the final state is detected. In general, for a kinematically complete situation, parity conservation does not require any of the analyzing powers to vanish;<sup>3</sup> however in special circumstances some important restrictions do arise.

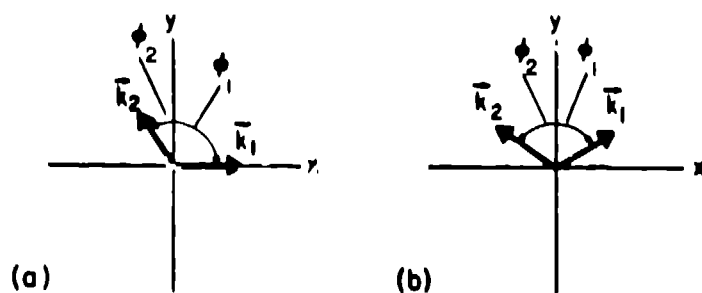


Fig. 1. Two possible y-axis definitions.  
In (a),  $\phi_1 = 90^\circ$ ; in (b)  $\phi_1 = \phi_2$ .

<sup>\*</sup>Work supported by the US Department of Energy.

The yield  $I$  for a reaction induced by a spin-1 beam can be written in the form

$$I = I_0[1 + (3/2)p_z C_z + (1/2)p_{zz} C_{zz}] . \quad (1)$$

In the analogous expression for a spin-1/2 beam, the coefficient of  $p_z$  is unity and the term involving  $p_{zz}$  is absent. In either case  $I_0$  is the unpolarized yield and  $C_z$ ,  $C_{zz}$  are linear combinations of the vector and tensor analyzing powers, respectively. The particular linear combinations which occur depend upon the orientation of the spin quantization axis with respect to the chosen coordinate system. In Figs. 2 and 3 we list the relationships between  $C_z$ ,  $C_{zz}$  and the analyzing powers for some common geometries. There the beam direction is out of the figure, the xy projection of the spin quantization axis is indicated by the heavy arrow, and the detector positions are also shown. Even though the symmetric choice for the y axis is depicted, the relations given in Figs. 2 and 3 are valid for any other orientation of the detectors.

$$\beta = 90^\circ$$

		$C_z$ (COEFFICIENT OF $\frac{3}{2}p_z$ )	$C_{zz}$ (COEFFICIENT OF $\frac{1}{2}p_{zz}$ )
	$\phi$ $0^\circ$	$A_y$	$A_{yy}$
	$90^\circ$	$-A_x$	$A_{xx}$
	$180^\circ$	$-A_y$	$A_{yy}$
	$270^\circ$	$A_x$	$A_{xx}$
	$45^\circ$	$-\frac{1}{\sqrt{2}}A_x + \frac{1}{\sqrt{2}}A_y$	$-\frac{1}{\sqrt{2}}A_{xy} - \frac{1}{\sqrt{2}}A_{xx}$
	$135^\circ$	$-\frac{1}{\sqrt{2}}A_x - \frac{1}{\sqrt{2}}A_y$	$\frac{1}{\sqrt{2}}A_{xy} - \frac{1}{\sqrt{2}}A_{xx}$
	$225^\circ$	$\frac{1}{\sqrt{2}}A_x - \frac{1}{\sqrt{2}}A_y$	$-\frac{1}{\sqrt{2}}A_{xy} - \frac{1}{\sqrt{2}}A_{xx}$
	$315^\circ$	$\frac{1}{\sqrt{2}}A_x + \frac{1}{\sqrt{2}}A_y$	$\frac{1}{\sqrt{2}}A_{xy} - \frac{1}{\sqrt{2}}A_{xx}$

Fig. 2. Coefficients of Eq.(1) for  $\beta=90^\circ$ .

We finally discuss two special situations. First, in coplanar geometry ( $\phi_1 = \phi_2 = 90^\circ$  in Fig. 1) parity conservation causes the same analyzing powers to vanish that vanish for two-body final states. Second, if identical particles are detected at equal polar angles, and if the symmetric choice of y axis is made [Fig. 1(b)], then parity conservation imposes an odd-even relationship on the analyzing powers at symmetric points on the kinematic locus (the curve in a two-dimensional plot of detected particle energies  $E_1$  vs  $E_2$  which indicates the energies permitted by conservation of energy and momentum). Thus, if we define an arc length  $s$  measured along such a





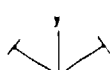
$\beta = 45^\circ$		
	$C_x$ (COEFFICIENT OF $\frac{1}{2} p_z$ )	$C_{zz}$ (COEFFICIENT OF $\frac{1}{2} p_{zz}$ )
(a)  $0^\circ$	$\frac{1}{2} A_1 + \frac{1}{2} A_2$	$A_{11} - \frac{1}{2} A_{22}$
 $90^\circ$	$-\frac{1}{2} A_1 + \frac{1}{2} A_2$	$-A_{11} - \frac{1}{2} A_{22}$
 $180^\circ$	$-\frac{1}{2} A_1 + \frac{1}{2} A_2$	$-A_{11} - \frac{1}{2} A_{22}$
 $270^\circ$	$\frac{1}{2} A_1 + \frac{1}{2} A_2$	$A_{11} - \frac{1}{2} A_{22}$
$\beta = 0^\circ$		
	$C_x$ (COEFFICIENT OF $\frac{1}{2} p_z$ )	$C_{zz}$ (COEFFICIENT OF $\frac{1}{2} p_{zz}$ )
(b)  UNDEFINED	UNDEFINED	$A_{11}$

Fig. 3. Coefficients of Eq. (1) for  $\beta = 45^\circ$  and  $0^\circ$ .

locus with an origin ( $s=0$ ) at a symmetric-energy point ( $E_1 = E_2$ ), then  $+s$  and  $-s$  refer to symmetric points on the locus at which the values for  $E_1$  and  $E_2$  are interchanged. The underlined analyzing powers in Figs. 2 and 3 are those quantities whose magnitudes are equal but whose signs are opposite at symmetric points ( $\pm s$ ), and the other analyzing powers have equal magnitudes and signs at symmetric points. This also implies the interesting result that the underlined analyzing powers vanish at symmetric-energy points ( $E_1 = E_2$ ).

1. Contributions to this symposium. See also R. E. Brown, G. G. Ohlsen, F. D. Correll, R. A. Hardekopf, and N. Jarmie, Bull. Am. Phys. Soc. 23, 953 (1978); F. D. Correll, G. G. Ohlsen, R. E. Brown, N. Jarmie, R. A. Hardekopf, and P. Schwandt, Bull. Am. Phys. Soc. 24, 569 (1979); F. D. Correll, R. E. Brown, R. A. Hardekopf, N. Jarmie, G. G. Ohlsen, J. M. Lambert, P. A. Treado, I. Slaus, and P. Schwandt, Bull. Am. Phys. Soc. 25, 556 (1980).
2. G. G. Ohlsen, R. E. Brown, F. D. Correll, and R. A. Hardekopf, Nucl. Instrum. Methods, to be published.
3. L. D. Knutson, Nucl. Phys. A198, 439 (1972).